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Components of a systems approach for the management of Queensland fruit fly *Bactrocera tryoni* (Froggatt) in a post dimethoate fenthion era

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ABSTRACT

Following the loss of two key pesticides, dimethoate and fenthion, producers and regulators need to develop new fruit fly management options. A systems approach is a likely measure in the post dimethoate and fenthion era. The risk of fruit fly can be mitigated at the regional, district and farm level. Some measures such as awareness and exclusion are common across all three levels. Pest control measures will be based on an understanding of climate, biology and pesticides. In this present paper, 28 different risk mitigation options that can be used in a systems approach in Australia are discussed.

1. Introduction

Tephritid fruit flies are important pests of fruit production throughout the world. In Australia, Mediterranean fruit fly (*Ceratitis capitata*) (Wiedemann) (Medfly) is an introduced pest and is the most important fruit fly on the west coast of Australia (Dominiak and Daniels, 2012). The native Queensland fruit fly (Qfly) *Bactrocera tryoni* (Froggatt) (Diptera: Tephritidae) is the most important pest in eastern Australia (Yonow and Sutherst, 1998) and is known to infest over 100 native and introduced hosts (Hancock et al., 2000; Oliver, 2007). The total annual export value for Australia's top 25 commodities that are fruit fly hosts was estimated at $432 million. Additionally, more than $1 billion worth of products traded domestically are susceptible to Qfly infestation. As a result, Qfly poses a major threat to national and international market access for horticultural commodities produced in eastern Australia (Plant Health Australia, 2008).

As a native Australian fruit fly, Qfly infested native plants before the arrival of European colonists. Drew (1989) proposed that Qfly bred in succulent fruits in tracts of tropical rainforests along the coastal areas of Queensland and possibly northern NSW. By 1819, many introduced hosts such as peaches, apricots, nectarines, grapes, oranges and pears were grown in coastal Sydney but no fruit fly problems were reported (Drew, 1989). As rainforests were cleared, Qfly expanded its host range to include imported cultivated fruits in the 1930's (Bateman, 1968; Edge et al., 2001; Maelzer, 1990; Gilchrist and Meats, 2009). Prior to laws controlling the movement of susceptible fruit, fruit flies were regularly distributed to all states (Jessup et al., 2007; Dominiak and Daniels, 2012). Regulatory controls continued to evolve into the current interstate market access arrangements (Jessup et al., 2007) but early horticultural producers were poorly prepared for fruit fly infestation and initial management measures relied on repellents (Dominiak and Ekman, 2013). Early measures used primitive pesticides such as the arsenical compounds. Increasingly more sophisticated synthetic pesticides became available after World War Two. The chlorinated hydrocarbons were followed by organophosphate pesticides. The past century of fruit fly control options was reviewed by Dominiak and Ekman (2013).

Dimethoate and fenthion became pivotal pesticides for both pre and post-harvest fruit fly control. With the recent restriction of dimethoate and fenthion use patterns for many horticultural crops (APVMA, 2011; Dominiak and Ekman, 2013; Clarke et al., 2011), there is a need to re-evaluate the range of options available for Qfly control in the post dimethoate-fenthion era. Many of the proposed measures have been available for decades but have not been utilised because of the low cost and high efficacy of dimethoate and fenthion.

2. Systems approach as a management strategy to support a standard

Crop losses due to arthropods, diseases and weeds have been estimated to be about 40% of production despite the intensification of pest control (Lewis et al., 1997). Sustainable agriculture and horticulture must be capable of maintaining productivity to feed a growing Australian and world population (Ikerd, 1993). Sustainable horticulture is fundamentally a systems approach to farm planning, production and decision making (Ikerd, 1993). The key to managing pests is knowledge of the pest biology (Ikerd, 1993; Lewis et al., 1997). Increasingly, pest management solutions will require a shift away from indiscriminate

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pesticide use to understanding the pest, promoting natural biological agents and evaluating their inherent strengths as components to total horticultural management system so that environmental, climatic and natural enemies keep the pests within acceptable population levels (Lewis et al., 1997; Dominiak et al., 2015a).

A systems approach is defined as an integration of different measures, at least two of which act independently, with a cumulative effect (FAO, 2012). Suppression or eradication success generally requires a combination of measures applied on an area-wide basis (Suckling et al., 2016; Vargas et al., 2015). The advantage of the systems approach is the ability to address variability and uncertainty by modifying the number and strength of measures to meet the appropriate level of phytosanitary protection. This will provide the confidence required by producers and consumers that the produce has acceptably low levels of infestation. Measures that do not kill pests but reduce their prevalence or reduce their potential for entry or establishment can be included in a systems approach (FAO, 2012; Dominiak et al., 2015a). This concept has been available for decades: Jones (1982) appears to be one of the first to describe the characteristics of a systems approach. Malavasi et al. (1994) claimed that these systems included monitoring, exclusion of pests and host fruit, community awareness and control of incursions. There were many similarities with integrated pest management measures at the regional, district and farm levels.

Since the 1940's with the development of the more modern pesticides, the preoccupation with the concept of zero pest populations has resulted in the search for “silver bullet” methods to eliminate pests. These measures often resulted in pesticide residues in food, pest resistance, secondary pests and pest resurgence due to the lack of natural control agents (Lewis et al., 1997). Insects became resistant to pesticides and required higher rates of application, or more frequent applications (Ikerd, 1993; Herron et al., 2014). Within Australian fruit production, these silver bullets were dimethoate and fenthion and were increasingly used as pre- and post-harvest treatments (Dominiak and Ekman, 2013).

The use of pesticides is considered increasingly unsustainable (Lewis et al., 1997) and it was suggested they should be the last rather than the first line of defence, particularly as pesticide use becomes increasingly restricted due to human health concerns (Dominiak and Ekman, 2013; Vargas et al., 2015). Pest management should use crop attributes and understanding pest biology to develop new crop production systems less dependent on pesticides. This type of measure will have benefits for sustainable production, farm workers and public health (Lewis et al., 1997).

For fruit flies, Jang (1996) defined a systems approach for quarantine security as an integration of pre- and postharvest practices used in production, harvest, packing and distribution of a commodity. These measures should cumulatively meet the requirements for quarantine security. A systems approach must demonstrate that each step in the system reduces the risk of pest damage or infestation in the commodity. Clarke et al. (2011) reviewed Australian management options for area wide management for large geographical areas. They noted the merits of understanding fruit fly biology to design or understand fruit fly management. The following 28 options in fruit fly management or risk mitigation provides the currently available control options. While the following applies primarily to Qfly, the principles can be used for any pest fruit fly in Australia or in any other country. A selection of several of these options could be combined into new domestic trade protocols (Jessup et al., 2007).

There is potential to develop these measures as international trade options however international trade agreements take many years to finalise. The domestic adoption of International Standards for Phytosanitary Measures, such as systems approach (this paper) is a mechanism to manage fruit flies to fulfil the requirements of an international standard. There are currently four standards and these are pest free areas (FAO, 2007), pest free place of production (FAO, 2006), pest free production site (FAO, 2006) and areas of low pest prevalence (FAO, 2008; Dominiak et al., 2015a; Jang et al., 2006). The adoption of the language and principles in these standards is likely to accelerate the transition of domestic market access protocols to international adoption. The current systems approach identifies measures to be applied at pre-planting, the growing period, harvest, post-harvest and handling, transport and distribution as measures applied to several stages. In this review, we identify 28 measures that can be applied at three levels; regional, district and farm. These can be applied to existing enterprises or to future planned enterprises.

2.1. Climatic limitation – day degrees

The Qfly life cycle is regulated by temperature and the accumulation of day degrees above a given temperature threshold. There are two temperature based models available: 380 day degrees above 12 °C (Yonow and Sutherst, 1998) or 315 day degrees above 11.5 °C (Anon., 1996). These can be used to predict the insect's life stage development. Southern parts of Australia accumulate fewer day degrees than areas further north. Regions with low day degrees do not permit high population levels and do not support prolonged or high population growth (Yonow and Sutherst, 1998). Areas that support fewer than three generations per year are unlikely to reach high populations (Clarke et al., 2011; Meats, 1981). In theory, these southern regions should require a less intensive control measures compared to warmer production areas further north. Areas of low pest prevalence may be more sustainable in cooler regions (Dominiak et al., 2015a). However, global warming may reduce the merits of this measure in some current marginal areas (Sutherst et al., 2000; Sultana et al., 2017). If new production sites are being considered, selecting areas that support fewer than three generations per year are likely to result in populations that are easier to manage (Clarke et al., 2011).

The southern boundary of *B. fraunfeldi* (Schiner), *B. neohumeraslis* (Hardy) and *B. jarvisi* (Tryon) were recently identified (Royer et al., 2016; Dominiak and Worsley, 2016, 2017) however traps are maintained to demonstrate continuing absence of these pests. Areas south of these identified ranges should be treated as pest free.

2.2. Climatic limitation (winter window) – flight threshold

Survival during winter for adult Qfly is poor in areas with an average yearly minimum temperature lower than 2.6 °C (Meats, 1981; Clarke et al., 2011). The flight threshold for Qfly is about 16 °C and flight is required for mating at dusk (Meats and Fay, 2000). Qfly only mate for about 30 min in the late afternoon (Tychsen and Fletcher, 1971). Temperatures below 16 °C at dusk prohibit flight and hence prohibit mating and this situation may be a trigger for a “winter window” for market access (Jessup et al., 2007). Female Qfly resorb their oocytes when temperatures remain below the 13.5 °C developmental threshold for several days (Fletcher, 1975) and the most advanced oocytes are resorbed first. Sperm in the spermathecae also are not retained over winter. Fruit harvested after the commencement of a “winter window” and before the spring flight temperature threshold may form the basis of domestic trade under a winter window scenario (Jessup et al., 2007). Females must remate in warmer spring weather to continue the life cycle. In regions where these cooler temperatures occur, a thorough control program in early spring is likely to break the Qfly life cycle. This measure may only be feasible in cooler climates.

Lower temperatures will also mitigate against fruit fly survival. Generally fruit fly travel from tree to tree in search of water, sugar and protein, and to escape predators. If the flight threshold is not reached for several days, Qfly are rarely known to live for more than two days without food and water (Fanson et al., 2014). The cold of winter offers a several management advantages for the control of fruit fly.

2.3. Moisture limitation

Available free moisture and increased humidity are important for Qfly survival (Dominiak et al., 2006; Yonow and Sutherst, 1998). At a regional level, populations decline during dry years and reach extremely high numbers during wet years (Bateman, 1968; Dominiak and Mapson, 2017). Drought stressed trees and fruit result in a high mortality rate for larvae and pupae. Bateman (1991) identified the line in New South Wales where agriculture was too dry to support Qfly populations: this line closely approximated the north eastern boundary of the Fruit Fly Exclusion Zone (FFEZ) (Anon. 1996). The zone below the line was established in the dry Riverina and Goulburn Valley areas because the climate is typically arid and did not support Qfly (Yonow and Sutherst, 1998). Crops grown in dry regions using water from irrigation schemes, such as the Mirrumbidgee Irrigation Area, are less likely to support fruit fly populations in dry seasons. Dry soils are known to be punitive on Qfly pupae (Hulthen and Clarke, 2006). However, in wet years, regular incursions are likely to result in a high survival rate and additional control measures are likely to be needed (National Climate CentreBureau of Meteorology, 2012; Sutherst et al., 2000; Dominiak and Mapson, 2017).

At a farm level, dry soils are known to be punitive on the survival of Qfly larvae (Hulthen and Clarke, 2006). Therefore the delivery of irrigation water, by devices such as drippers, in small areas will minimise opportunities from Qfly pupae to survive to adulthood. Dry air is also punitive to Qfly and they must rehydrate by accessing free water. Irrigation techniques, such as overhead sprinklers, that provide high humidity and free water will increase the survivability of Qfly. Besley (1962) reported that Qfly needs only 5 μL of water to fully restore their hydrated state and this can be consumed within minutes. Flooding soils, either naturally or by irrigation, is unlikely to retard Qfly as pupae are known to survive long periods of anoxia (Dominiak et al., 2011b). This may be due to their development in wet soils in sub-tropical rain forests. Overhead sprinklers increase the humidity of the orchard area enhancing fruit fly survival and also promote the growth of bacteria and fungi in the tree canopy. These organisms provide food for fruit flies and this extends their life span and increases the likelihood of reaching sexual maturity or nourishing the formation of eggs (Dominiak, 2012). If Qfly cannot find water and food, they are likely to die after 48 h (Fanson et al., 2014; Dominiak et al., 2014a). Any irrigation strategy that minimises the chances of fruit fly survival would assist a systems approach to pest management.

2.4. Flight dispersal limitation – geographic isolation

Most authors claim that adult Qfly disperse relatively short distances, generally less than 1 km (Bateman, 1991; Dominiak et al., 2011a; Gilchrist and Meats, 2011; Maelzer, 1990; Meats, 1996; Meats and Edgerton, 2008; Meats et al., 2003a; Weldon and Meats, 2010). At a regional level, Qfly are unlikely to fly between rural centres which usually are more than 50 km apart. Long distance natural dispersal of Qfly has been linked to isolated favourable habitats separated by resource poor country that forced dispersing flies to make longer flights (Fletcher, 1974; Meats and Edgerton, 2008). Bateman (1991) reported that Qfly tended to remain in the vicinity of fruit trees.

Resource poor conditions rarely exist in larger urban areas due to the residential garden or landscape water use (Fletcher and Bateman, 1982; Raghu et al., 2000; Dominiak et al., 2006) or in managed orchard situations where there is little incentive for the flies to abandon safe havens with water and abundant fruit. Consequently dispersal distances are likely to be relatively short in these favourable habitats. Insects, including fruit flies, require energy to fly and resource poor environments rarely provide sugar or energy for longer flights. Qfly need a diet in the correct balance between sugar and protein to sustain flight and maturation (Fanson and Taylor, 2012). Dominiak (2012) claimed the natural dispersal rarely exceeded 2 km with most flies being trapped within 600 m of the release sites. Based on short dispersal distances, geographic isolation will be important for some more isolated crop production sites. Qfly dispersal follows the typical long distance jump followed by local dispersal (Sadler et al., 2011). The long distance jump is usually the human assisted transportation of infested fruit (Dominiak et al., 2000; Dominiak, 2012). In south eastern Australia, wind is not known to disperse Qfly (Dominiak, 2012; Dominiak et al., 2013). Geographic isolation therefore is a strong component of any systems approach.

At the district level, there may be merit in the town-orchard split. Urban areas have microclimates with higher moisture and temperatures (Fletcher and Bateman, 1982; Dominiak et al., 2006; Torok et al., 2001; Yonow and Sutherst, 1998). Qfly populations are more likely to survive in urban areas where there is a continuum of hosts. Bateman et al. (1966) reported that larger towns had larger numbers of fruit and a wider variety of fruit trees. Towns also have higher temperature and humidity than rural areas (Dominiak et al., 2006; Torok et al., 2001). Qfly are unlikely to leave urban areas that offer water, food, shelter and host fruits to continue the life cycle (Raghu et al., 2000). Orchards are generally monocultures and once the fruit is harvested, there is no host fruit to allow the fruit fly life cycle to continue. Orchards also do not have an urban heat island (Torok et al., 2001). These attributes, along with the recognition of a shorter dispersal distances, would be a good basis for recognizing a town/orchard split for Qfly populations. Additionally Qfly are known to be carried with humans in infested fruit and the human population per unit area is much higher in urban areas than in orchards. Monitoring arrays are more intense (400 m) in urban area compared with orchard arrays (1000 m). Rigot et al. (2014) reported that diverse and open habitats (as occur in urban areas) provide better resistance to biological invasions than monocultures (such as orchards). Landscapes with a diversity of host and non-host accelerated the spread by up to 13% and hence contributed to over dispersal and mitigated against establishment. The recognition of the relative difference between urban and orchard environment and resources may assist in the development of domestic trade agreements.

2.5. Favoured sites in the landscape

Knowledge of preferred sites in the landscape and mating habits can be used to support existing programs. Qfly tend to remain in the vicinity of fruit trees (Bateman, 1991). Qfly appear to congregate at the bottom of slopes (Worsley et al., 2008; Dominiak et al., 2013). Water flows down-slope or accumulates at the bottom of slopes. Fruiting trees in these areas are more likely to be well hydrated and provide more fruit with good hydration, optimising fruit fly survival. These fruits are likely to result in larger pupae and these in turn have higher emergence rates (Dominiak et al., 2012). Qfly adults generally disperse along tree or waterway corridors (Meats, 1983; Meats et al., 2003b; Clarke et al., 2011; Dominiak et al., 2011a) and these sites need to be treated more frequently. Additionally feral or host trees should be removed to minimise fly survival.

Many crops have an edge effect where Qfly move between the edge of the crop and vegetation just outside the crop (Balagawi et al., 2014a). Growers could treat the edges of crops more frequently and thereby minimise the likelihood that Qfly would enter the centre of production blocks. Where permitted, off-farm vegetation could also be treated. This treatment of favoured sites would enhance the exclusion strategy and minimise the need to treat production areas.

Orchard properties often have small homestead fruit trees near the residence to provide fruit other than what is grown commercially. These homestead fruit trees need to be managed equally intensively as commercial trees. If not well managed, these homestead orchards become defacto feral trees and should be removed. Fruit should be stripped from feral or unmanaged trees (Fletcher and Bateman, 1982). Feral trees may be sprayed at flowering time to induce floral abscission, thus preventing the development of fruit (Campbell pers. com., 2011).

In Hawaii, sanitation has been used with bait sprays to control *Bactrocera dorsalis* (Hendel) and *B. curcurbitae* (Coquillette) (Jang et al., 2008; Pinero et al., 2009).

2.6. Managing hosts other than the crop (feral tree removal)

Feral trees, including abandoned orchards, act as a possible haven for Qfly because no control measures are used to suppress fruit fly populations. Qfly is an arboreal pest and attracted to tree shaped objects (Meats, 1983). Feral trees are often volunteers and are frequently solitary trees on public property such as road sides or irrigation channels. While feral trees are often isolated, they may support Qfly movement along tree corridors (Bateman et al., 1966). Conversely Rigot et al. (2014) claimed that solitary well-dispersed host trees were less likely to be detected by pest species and colonised because of the visual and semichemical disruption caused by solitary trees. Alternatively abandoned orchards or poorly managed fruit trees can also act as a large haven for Qfly. Managers need to be aware of usual hosts such as osage orange (*Maclura pomifera* (Raf.) Schneid) (Reynolds et al., 2015) and rose hips (Dominiak, submitted). Olives (*Olea europeana* L.) can support fruit fly populations at the same level as some citrus cultivars (Dominiak, submitted). Grapes (*Vitis sp.*) can be occasional hosts for Qfly when other preferred hosts are not available (Dominiak, 2011). These havens need to be removed or managed.

2.7. Exclusion of risk fruit movements

The most common method that Qfly is spread to new areas is in infested fruit carried primarily by travellers (Bateman, 1972) and possibly in infested commercial consignments. Once it has been transported and established in previously uninfested areas, Qfly can fly short distances from host to host, often along tree or host corridors (Dominiak et al., 2013; Sadler et al., 2011). Therefore it is important to minimise or prevent this human assisted transport. Florec et al. (2013) claimed there was economically more value in exclusion than in monitoring or eradication. Dominiak et al. (2000) reported that the travelling public carried about 55 infested consignments annually across Victorian state borders at 4 sites. Tomatoes were the most frequently infested produce (about 50%). Within New South Wales on the entry of the Fruit Fly Exclusion Zone, up to 17% of the travelling public carry fruit (Dominiak et al., 1998) some of which may be infested. Dominiak et al. (2001) reported 14% of travellers carried host fruit into a fruit fly free area despite road signs warning travellers of financial penalties.

Interstate host regulation will always be a vital component in fruit fly management. Fruit flies were originally distributed across Australia by unregulated movements of interstate produce (Dominiak and Daniels, 2012). All Australian States now regulate host produce using the Interstate Certification Assurance (ICA) scheme (Jessup et al., 2007). The distribution of Qfly and other pest fruit flies have remained stable in Australia for 70 years due largely to these exclusion practices (Dominiak and Mapson, 2017).

At a farm level, this requires that farm managers ensure that farm workers, service personnel and contractors do not carry infested fruit onto the farm. This strategy should be linked to signs at entry points informing visitors that the farm is a biosecure enterprise and that bringing fruit onto the farm is forbidden.

2.8. Use of genetics to understand long distance movements

In the early 1990's, there was a perception that fruit flies could naturally disperse many kilometres, possibly 100's of kilometres (Dominiak, 2012). Recently it has become recognised that long distance dispersal is usually due to human assisted activities (Jessup et al., 2007; Dominiak and Coombes, 2009). Genetic techniques can be used to help find the source of incursions and hence to design management strategies to prevent these future long distance movements. Gilchrist et al. (2006) found most incursions into the quarantine zone originated from the Risk Reduction Zone and generally within 200 km of the incursion detection site. This knowledge resulted in awareness programs becoming more locally targeted instead of the regional and interstate programs that were originally planned. If the genetic tests demonstrate long distance origins, the source of the breach can be predicted using genetics and remedial action undertaken to prevent commercial consignments becoming source of incursions (Jessup et al., 2007).

In New South Wales, genetic techniques have demonstrated a mostly north to south movement of Qfly (Chen et al., 2016) while in Victoria, the movement tends to be more east to west (Blackett et al., 2017). Sherwin et al. (2015) studied the invasiveness of Qfly and suggested that outbreaks in southern eastern Australia were derived from genetically differentiated populations over-wintering in or near the outbreak areas. This knowledge may assist in developing risk mitigation strategies in or near outbreak areas. Gasperi et al. (2002) used genetics to understand the bioinvasion of Medfly across Africa and the Mediterranean region, and in Australia with the flow from the Western Australia towards South Australia (Bonizzoni et al., 2004). Understanding these genetic flows enables effective measures to be developed to prevent pest flies entering production areas.

2.9. Awareness

A good awareness program for tourists and regular travellers into the production districts is an important regional tool. Kruger (2016a) noted that disconnecting the technical aspects of a successful program from the social and institutional aspects can create unrealistic expectations. The concepts of social learning, communication, adaptive capacity, shared decision-making and shared authority make valuable contributions to collaborative pest management and awareness strategies, particularly for industry driven programs (Kruger, 2016b). These programs also need to deal with free riders or social loafers while pursuing improved market access by the larger community (Mankad unpub.).

Awareness will minimise the chances that infested produce might be carried by non-local travellers into otherwise fruit fly free areas (Jessup et al., 2007). Most travellers were usually compliant with host movement restrictions if they knew what to do (Dominiak and Coombes, 2010). Regional awareness strategies were frequently combined with roadside vehicle inspections (Dominiak and Coombes, 2009). Television advertising was frequently more successful on local residents while radio was more effective for non-local travellers. Newspapers and journals had a small target audience (Dominiak and Barchia, 2005a). Awareness alone had a small impact on reducing fruit movements but the impact was much higher when linked to financial penalties (Dominiak et al., 2005). The use of spot fines without an awareness program also had virtually no impact on travellers (Dominiak et al., 2001, 2005). However the combination of awareness programs and financial penalties reduced fruit carriage from 18% down to 3% at some sites (Dominiak and Barchia, 2005b). Travellers originating from within the quarantine zone were less likely to carry fruit because of their familiarity of the requirements advertised in local awareness programs (Dominiak et al., 2001).

Accidental carriage of infested fruit is the most recognised method that Qfly is moved into pest free farms. Information packages could be developed to educate farm workers on the restrictions when entering production districts and should be a condition of employment. Most farm visitors did not consider the farm as a biosecure enterprise and were usually unaware of risks their actions may pose to the producer's viability or trade status. Biosecurity signs on property boundaries and entry points are likely to increase awareness of all visitors including family members and workers. Information packages for seasonal workers would educate these visitors to the requirements of entry onto the farm. These requirements may include the prohibition of the carriage of fruit (possibly infested) onto the farm. This education of

workers can also lead to early detection of incursions or identification of risk pathways if workers know to look for these things.

2.10. Surveillance

Suckling et al. (2016) noted that surveillance was important both for early detection and delimiting in incursions. In relation to the later, surveillance at a regional level can demonstrate that exotic fruit flies are not in a production area. In Australia, fruit fly surveillance is conducted in all jurisdictions, primarily for early detection of exotic incursions and to delimit species distribution (Anderson et al., 2017). Vargas et al. (2015) reviewed the pestiferous fruit flies in the Pacific region and Australia. Many species are not known to exist in Australia and Australian production areas can be declared free from those species (Jessup et al., 2007). Similarly, there are some tropical species found only in northern Queensland such as *B. frauenfeldi* (Schiner) (Royer et al., 2016), *B. jarvisi* (Tryon) (Dominiak and Worsley, 2017) and *B. cucumis* (French) (Dominiak and Worsley, 2018); sub-tropical areas are deemed free from these species. *Bactrocera neohumeralis* is not detected south of Sydney or in inland New South Wales (Dominiak and Worsley, 2016). Similarly, Medfly has not been detected in eastern Australia for 60 years but surveillance is maintained (Dominiak and Mapson, 2017). Early detection greatly increases the likelihood of eradication because the incursion propagule is small (Tobin et al., 2014).

However, within endemic regions, monitoring must be ongoing to ensure that the endemic pest distribution has not shifted due to climatic or other changes and that incursions are detected early (Sutherst et al., 2000). In south eastern Australia, Qfly is endemic (Dominiak and Mapson, 2017). The Fruit Fly Exclusion Zone was developed to assist export market access and Qfly was eradicated from that area (Yonow and Sutherst, 1998). Regular monitoring was used to demonstrate that the region remained free from Qfly (Dominiak et al., 2003; Gillespie, 2003; Osborne et al., 1997). This Zone was disbanded in July 2013 (Dominiak and Mapson, 2017) and going monitoring is used to support new standards for pest free place of production, pest free production sites or areas of low pest prevalence (Dominiak et al., 2015a). Regional monitoring can also be used to demonstrate absence of exotic species (Dominiak and Daniels, 2012; Vargas et al., 2015; Royer et al., 2016).

At a district level, monitoring within production districts will be a critical tool to demonstrate fruit fly is present or confidence of absence (Dominiak et al., 2003; Dominiak and Nicol, 2010). Since the 1960s, Qfly monitoring has relied on cuelure and malathion up to the current time (Anon., 1996; Bateman et al., 1966; Brieze-Stegeman et al., 1978; Cowley et al., 1990; Dominiak et al., 2003; Jessup et al., 2007; Lloyd et al., 2010; Meats et al., 2002; Osborne et al., 1997; Worsley et al., 2008; Yeates et al., 1992). Some research has shown lures can be improved (Drew and Hooper, 1981; Dominiak et al., 2011c; Dominiak et al., 2015b; c; Royer et al., 2014) and more work needs to be conducted to optimise lures for monitoring and male annihilation technique.

At a farm or production site level, monitoring within production areas will be a critical tool on which control programs are based (Dominiak et al., 2003; Dominiak and Nicol, 2010). The chances of eradication are greatly increased by monitoring and early detection (Suckling et al., 2016) and the early deployment of control measures. Male Qfly are more likely to be trapped in certain host trees (eg apple trees) and these optional host trees should be used where possible (Mo et al., 2014).

The threshold for a Qfly outbreak and suspension zones distances was reviewed for pest free areas (Dominiak et al., 2011d; Dominiak, 2012) and similar thresholds have been adopted for areas of low pest prevalence under different trapping intensities (Dominiak et al., 2015a; FAO, 2008). Compared with cuelure baited traps, wet food lures in McPhail traps are much less effective at trapping male and female Qfly (Dominiak et al., 2003; Dominiak and Nicol, 2010). Monitoring within production areas will be a critical tool for future control programs.

2.11. Mass trapping

Mass trapping is a combination of surveillance and the male annihilation technique. This is a relatively new attract-and-kill technique developed overseas (e.g. Greece, Reunion Island, Spain), particularly for Medfly and summarised by Rahman and Broughton (2016). Mass trapping for Medfly may use male or female lures and trap design can significantly influence results (Navarro-Llopis et al., 2008). In Western Australia, mass trapping is being assessed as a control measure for Medfly in the Australian context. When used alone, mass trapping reduced crop losses to 2–5% which was considered unacceptable (Rahman and Broughton, 2016). Similar to male annihilation technique, mass trapping was much more effective when combined with bait spraying or cover spraying. The relatively high cost in Australia often results in application at rates lower than recommended (Rahman and Broughton, 2016). Australian options for mass trapping for Medfly and Qfly was reviewed by Dominiak et al. (2016) however there are no published reports on mass trapping for any other Australian fruit flies.

2.12. Repellents - exclusion

Repellents were originally used at the turn of the 1900s but replaced by pesticides. Repellents and attractants can be used in combination however the attractant should be positioned outside of the repellent to optimise the pull-push measure (Meats et al., 2012). Mineral oils were repellent (Nguyen et al., 2007) and repellent sprays around property boundaries may become part of a systems approach (Meats et al., 2012). Hidayat et al. (2013) found essential oils repelled female Qfly but only persisted for only several hours. Within production areas, horticultural mineral oil does not adversely impact soil dwelling arthropods while some pesticides are likely to cause reductions in some predators (Liang et al., 2007). The application of gibberellic acid has been reported to disrupt host recognition and hence to reduce infestation rates by *Anastrepha ludens* (Loew) (Birke et al., 2011). Calcium chloride has been demonstrated to inhibit oviposition (Eisemann and Rice, 1985). The inclusion of repellents, particularly as a perimeter treatment, could minimise the need to treat for fruit flies in a systems approach.

2.13. Mechanisms to confuse host recognition

Qfly are attracted to tree shaped objects so any mechanism to disrupt the tree shape will be an advantage to minimise the entry of Qfly into orchards (Meats, 1983). Mesh fences (Lloyd et al., 2005) or kaolin sprays (Alavo et al., 2010) have been shown to be useful techniques to confuse insect identification and selection of host trees by fruit flies (Mazor and Erez, 2004; Saour and Makee, 2004). Mesh enclosures provide protection from a range of threats such as birds, hail and insects. Netting of a 2 mm mesh will exclude fruit flies however mesh colour is important.

Qfly also are attracted to certain colours. Meats (1983) conducted trials using fluorescent colours and claimed that yellow was the most attractive single colour, followed by green and red. Black was the least attractive single colour but the attractiveness of black combined with yellow or green increased many times when combined in a chequerboard pattern. Blue and white were also relatively unattractive as a single colour but also increased attractiveness when combined with yellow or green in a chequerboard pattern. Hill (1986) claimed yellow and yellow green sticky balls attracted male and female Qfly. Hill and Hooper (1984) also claimed daylight fluorescent Saturn Yellow caught more fruit flies than other colours although Lime, Blaze Orange and Emerald were also attractive. Yellow and yellow/green consistently caught more flies when combined with cuelure. Weldon (2003) claimed Qfly were equally attracted to the colours of fluorescent yellow or green. Collins et al. (2008) found Qfly were less attracted to white mesh compared with green mesh. White mesh fencing could be used as an

effective way to interfere with the tree selection process of Qfly (Fletcher and Bateman, 1982). Yellow or green mesh fences are likely to attract Qfly into the immediate area. Knowledge of these preferences could be used to design treatments to interfere with the recognition of potential host trees by fruit fly. Pinero et al. (2017) reported that for *B. curcurbitae* (Coquillet) vision seemed to be the main mechanism host recognition.

2.14. Sanitation (crop hygiene)

Removal of fallen fruit has been a standard crop protection measure for a century (Dominiak and Ekman, 2013; Vargas et al., 2015). Where this is not economical, fallen fruit could be damaged with rollers or slashers to facilitate attack by breakdown organisms. Vinegar fly infestations are known to decrease survivability of *B. tryoni* in larval media (Balawai pers. comm.). In a mixed cropping situation, Hetherington (2011) demonstrated that unpicked cherries harboured fruit fly for the following apple crop.

2.15. Male annihilation technique - exclusion

Male annihilation technique (MAT) is an “attract and kill” technique and has been used since the 1960's (Skepper and Sweedman, 1968). MAT has been used in all Australian states (Madge et al., 1997; Bradshaw and Scott, 1992; Dominiak et al., 2006; Lloyd et al., 1998, 2010; Hetherington, 2005). High doses of cuelure did not repel Qfly (Dominiak et al., 2009) and therefore high cuelure doses can be applied to MAT to prolong field life. Even at traditional doses, MAT remains active for at least 12 months and may contribute to an exclusion barrier around production sites (Bradshaw and Scott, 1992; Dominiak et al., 2009; Dominiak and Nicol, 2012; Madge et al., 1997). This technique eliminates a very high proportion of males from the population. Weldon (2007) demonstrated that female *B. tryoni* visited larger male aggregations more frequently than single males because of the higher number of calling males. MAT reduces the chances of a mating.

MAT will not control Qfly populations by itself. This technique is best combined with other control techniques as female *B. tryoni* may still have chance encounters with single males (Weldon, 2007). MAT is ideal to suppress Qfly populations in isolated towns and its impact appears to be better early in the season (Clarke et al., 2011). MAT has been used for mainly for cuelure attracted flies. However, MAT has been used to assist in the eradication of the methyl eugenol attracted *B. papaya* (Hendel) in north Queensland (Lloyd et al., 1998) and evaluated in Tahiti (LeBlanc et al., 2011). Methyl eugenol MAT can reduce *B. dorsalis* populations by 99.5% (Ndlela et al., 2016).

At a regional level, MAT was deployed throughout the Risk Reduction Zone to minimise the chances of an incursion into the adjacent Fruit Fly Exclusion Zone. At the farm level, MAT may be used as part of the “pull-push” perimeter treatment to minimise the entry of fruit flies into a production site (Meats et al., 2012) and hence minimise the need to treat for fruit fly within the production sites.

2.16. Oviposition limitation

Qfly has a relatively blunt ovipositor and prefers to lay eggs in existing skin lesions (Allman, 1939). Female *B.tryoni* land on fruit and explore the surface for favourable oviposition sites such as holes made by any agent (Pritchard, 1969). Fruit with skins that were too smooth, oily or tough were abandoned as the ovipositor can neither grip nor penetrate the fruit (Pritchard, 1969). Vegetable oils created a slippery surface on fruit skins and female Qfly were unable to make punctures in the fruit for egg deposition (Hidayat et al., 2013). However it is likely that this mechanism would be less successful if the fruit skin was already damaged or broken. Escaping respiration gas such as carbon dioxide is a strong stimulus for Qfly oviposition (Stange, 1999). Bateman (1991) recognised seven fruit as being a host only if the skin was broken. Any measures that minimise fruit skin damage from adverse weather (such as hail), birds or other insects will minimise egg laying opportunities for Qfly, particularly in hard skinned fruit (Tracy et al., 2007).

2.17. Host susceptibility

Hosts that are less likely to be infested should not require the same level of protection as recognised or preferred hosts (Jessup et al., 2007). Bateman (1991) and subsequently Anon. (1996) recognised four levels of host susceptibility. Fifty-nine hosts were recognised as needing disinfestation if grown in Qfly endemic areas. Five hosts were recognised as being a non-host if harvested in a green state and seven were recognised as only being a host if the skin was broken. Eight others were claimed as non-hosts, however grapes (*Vitis* spp.) have since been recognised as occasional hosts (Dominiak, 2011). Grapes become hosts under high Qfly populations (Clarke et al., 2011) and this scenario is likely for many marginal hosts. Olives were originally considered a non-host for Qfly (Bateman, 1991) however recent evidence also indicates that olives are a host in certain conditions (Mellberg and Dominiak, unpub). Rose hips have also recently been detected as hosts of *B. tryoni* however this may only be a late season occurrence (Dominiak and Galvin, unpub.). Lemons were the least preferred citrus host while Murcott and grapefruit were the most preferred; Navel and Valencia oranges with found to be intermediate (Muthurthantri and Clarke, 2012). Characteristics such as fruit size, peel toughness and Brix level influenced oviposition. Hancock et al. (2000) examined historical records and databases in a review of host status however some historical records were of questionable status. Lloyd et al. (2013) found the same range of host susceptibility using a host susceptibility index. Citrus hosts were less susceptible than hosts such as guava, mulberry, loquat, and pears. Grosse Lisse and Roma tomato cultivars were highly preferred hosts for *B. tryoni* (Balagawi et al., 2005). The pericarp toughness of cherry tomato cultivars appeared to be responsible for a low rate of infestation. Oviposition preference of Qfly did not vary across host families but overall fitness did (Balagawi et al., 2013). Balagawi et al. (2013) also reported a variation of oviposition preference within host families. The host susceptibility may be influenced by abundance of alternative host fruit in the environment (Clarke et al., 2011). However if Qfly populations become high, even non host fruits may become attacked (Dominiak, 2011).

Susceptibility infers the likelihood of being stung. The host utilisation is a similar issue but different as it refers to survival and utilisation after being stung: this concept was suggested by Muthurthantri and Clarke (2012). Unharvested apples resisted the development of Qfly larvae, particularly in slow ripening and late season varieties (Bower, 1977). Larvae rarely survived beyond the first or early second instar. Lower overall fitness was attained on zucchini as compared to higher fitness levels obtained on apple, guava and tomatoes. Utilisation and survival of larvae may depend, at least partly, in the water soluble carbohydrate (Dominiak and Fanson, 2017). Further research needs to be conducted to align earlier work on host preference and host utilisation with current international standards.

2.18. Bait sprays

Malathion and protein bait was recommended as an alternative to DDT in bait sprays in the 1960s (Anon., 1960; O'Loughlin, 1964). Protein and malathion bait sprays had extensive use as a whole town treatment in 48 towns in New South Wales (Skepper and Sweedman, 1968). Protein and malathion continues to be used in bait sprays to the current day in all Australian states (Anon., 1996; Madge et al., 1997; Sproul, 2001; Cantrell et al., 2002; Lloyd et al., 2010; Mooney et al., 2011; Hetherington, 2005). The placement of bait sprays should be at about 1.5 m above ground for maximum effectiveness (Balagawi et al., 2012). Bait sprays may be more effective if application time is in the

peak response time between 12.00 and 16.00 (Balagawi et al., 2012; Dominiak et al., 2014b). Many adult flies can find protein sources in the environment and hence are not well attracted to protein bait spray. However bait sprays are most effective on newly emerged flies as they are most likely to be protein hungry (Balagawi et al., 2014b). Trichlorfon and chlorpyrifos are alternative pesticides (Hetherington, 2005) but are not commonly used. The spray schedule may need to be adjusted according to the pest pressure and pesticide residue requirements. Bait sprays alone will not control high Qfly populations and other measures need to be combined with bait sprays (Hetherington, 2005). Bait sprays have been used successfully in combination with male annihilation technique.

There have been few new pesticides approved for fruit fly bait sprays since 1960's. Spinosad is successfully used as part of the systems approach in Queensland (Lloyd et al., 2010). Spinosad is a new pesticide however it appears to have a shorter life in the field than malathion. Additionally resistance has already developed in olive fruit fly in California (Kakani et al., 2009) and in insects in Australia (Herron and Langfield, 2011). Spinetoram is replacing spinosad in some management programs but resistance to spinosad is likely to result in resistance to spinetoram (Herron et al., 2014). If spinosad and spinetoram use declines for fruit fly control for whatever reason, producers will be obilged to rely on pesticides that have been in use for over 60 years. While malathion has been used for decades, Reynolds et al. (2017) identified many other pesticides that were effective on Qfly for possible future use.

2.19. Cover sprays

Dimethoate and fenthion were first recommended as cover sprays in the mid 1960s. These pesticides overcame most of the undesirable features of DDT (Dominiak and Ekman, 2013) and became used increasingly in most control programs. O'Loughlin (1964) reported that dimethoate and fenthion killed larvae developing in fruit. Dimethoate and fenthion were significantly more effective than trichlorfon (Bateman, 1991). Dimethoate and fenthion were recommended cover sprays in the FFEZ and RRZ (Anon., 1996) and remained part of most eradication and control programs until recently (Mooney et al., 2011; Sproul, 2001; Hetherington, 2005; Jessup et al., 2007). The Australian Pesticides and Veterinary Medicines Authority reviewed dimethoate use patterns and many pre harvest use patterns have been withdrawn (APVMA, 2011). Dimethoate was permitted on a small range of crops that do not have an edible peel. Fenthion use patterns are currently under review and pre-harvest use patterns have been decreased (Dominiak and Ekman, 2013). Dimethoate and fenthion use patterns have decreased due to residue issues and human health concerns in treated produce. However these pesticides may be used in field after harvest to kill flies in the orchard before winter to minimise overwintering adults.

2.20. Sterile insect technique or biological control agents

Isolated areas may be able to use inundative release of sterile Qfly or augmentative releases of parasitoids as part of the Systems Approach (Reynolds et al., 2010; Dominiak et al., 2011a; Meats et al., 2003b; Spinner et al., 2011). The sterile fly technique is more likely to be successful when wild populations are low (Jessup et al., 2007; Meats, 1996). Sterile Qfly disperse an average distance of about 200 m (Dominiak, 2012; Dominiak et al., 2013) and therefore a release program requires many release points to gain a uniform distribution across the landscape. This results in added cost for the distribution program. Unlike pesticides, sterile flies influence wild populations well distanced from the treatment site. Managers need to assess the relative merits of pupal, adult and chilled adult release as each release technique has different distribution characteristics (Dominiak et al., 2011a; Reynolds and Orchard, 2015). Also, roving release and static release also result in different distribution characteristics so the release method needs to be chosen that meets the needs of the production site (Reynolds and Orchard, 2015).

In some areas, natural controls exist for wild Qfly such as weaver ants, *Oecophylla smaragdina* (Fabricius) (Hymenoptera: Formicidae), that have been shown for control *B. jarvisi* (Tryon) in the Northern Territory (Peng and Christian, 2006). Nematodes have been shown to adversely impact fruit flies but are yet to be used commercially (Langford et al., 2014). The potential use of biological control was reviewed however none have been developed to a useable component of a management program (Spinner et al., 2011). Where these natural controls are viable, these natural control agents should be encouraged by supplementary feeding to encourage population growth.

2.21. Under tree chemical treatments

Under tree treatments of infested trees has been used since before 1900 (Benson, 1895; French, 1898; Lea, 1898; Froggatt, 1897). Originally lime and kerosene were used. After World War II, chlorinated hydrocarbon pesticides (DDT, Lindane, etc) were used extensively in this role throughout Australia (Ryan, 1950; Madge et al., 1997; O'Loughlin, 1964) up to 1985. In 1987, organochlorine pesticides were replaced by chlorpyrifos that remains the standard under tree treatment in the FFEZ and South Australia (Madge et al., 1997; Anon., 1996) and in the Pacific region (Vargas et al., 2015). However, chlorpyrifos was one of the least persistent pesticides in the soil (Horwood, 2007). The effectiveness of chlorpyrifos or alternative pesticides needs to be researched further. Currently lambda-cyhalothrin is being evaluated as a possible replacement for chlorpyrifos. Stark et al. (2014) identified several insecticides effective against fruit fly as soil drenches in America which may have merit in Australia.

3. Post harvest treatments

3.1. Methyl bromide disinfestation

Methyl bromide (MB) was highly effective against fruit fly eggs in tomatoes and resulted in very little damage (Rigney and Gellatley, 1973). Singh et al. (1976) reported on the effectiveness of MB in the treatment of bananas, capsicums, cherries and apples. Hargreaves et al. (1978) and Singh et al. (1976) claimed that fumigation with MB resulted in the formation of inorganic bromide residues. Jessup et al. (1994) noted that MB was approved as a fumigant against pests such as fruit flies. The use of reduced levels of MB was developed to disinfest cherries (Jessup, 1988). Methyl bromide could be phytotoxic to citrus and could shorten shelf life (DeLima et al., 2007). Use in Australia could become restricted because MB is an ozone depleting gas and was subject to phase-out under the Montreal Protocol (Jessup et al., 1998a; DeLima et al., 2007).

3.2. Chemical disinfestation

Dimethoate and fenthion dips inhibited the development of Qfly larvae in bananas and killed larvae already present in the fruit (Anon., 1963; Braithwaite, 1963). Dimethoate dipping of tomatoes was developed because MB and ethylene dibromide (EDB) treatments caused fruit damage (Swaine et al., 1984). With the phasing out of EDB worldwide, the use of dips and packing line flood treatments using dimethoate and fenthion was developed for mangoes (Heather et al., 1991). This treatment became popular with producers of a range of commodities because producers could conduct the treatment themselves in packing sheds and produce did not have to be sent away to commercial providers for disinfestation. Swaine et al. (1984) also reported on dimethoate residues in tomatoes after treatment. Dimethoate and fenthion could disinfest tomatoes with the same level of security as EDB but without the phytotoxicity or tainting effects (Heather et al., 1987). Fenthion was

more efficacious against Qfly than dimethoate when used post-harvest but residue levels of both insecticides were below the relevant residue limits (Heather et al., 1987). Chemical fumigants and insecticides were gradually replaced by residue-free methods of disinfestation (Corcoran, 1993). However, due to human health concerns, the use of dimetaote and fenthion has been restricted to produce mainly with an inedible peel (Dominiak and Ekman, 2013).

3.3. Irradiation disinfestation

Irradiation has been developed for several export commodities against fruit flies and used as a phytosanitary treatment in Australia (Heather et al., 1991; Hallman and Loaharanu, 2002; Hallman and Thomas, 2010). The efficacy of irradiation may be influenced by the level of oxygen or air temperature at the time of irradiation (Hallman, 2004). Irradiation time may be shortened for some fruit fly species by heating or cooling consignments before treatment (Hallman et al., 2011). With the fears of terrorism, gamma irradiators are likely to be replaced by X ray irradiators with equivalent efficacy (Mastrangelo et al., 2010). However, its acceptance by Australian consumers is yet to be tested extensively. The possible widespread use of irradiation may be delayed due to the lack of irradiation facilities, particularly in or near production areas. However New Zealand now accepts irradiated apples, apricots, cherries, honeydews, nectarines, peaches, plums, rock melons, strawberries, table grapes, zucchinis, scaloppini and summer squash to remove the potential threat of fruit fly (Anon., 2015). Irradiation is often termed “cold pasteurisation” as it leaves no residues and does not alter nutrient component. Treated consignments are not heated or cooled during treatment and treatment can be done at any temperature. Irradiation use in Australia was reviewed by Haynes and Dominiak (2018).

3.4. Cold disinfestation

Hill et al. (1988) reported on the use of cold disinfestation for oranges, and this treatment has been developed for other commodities (Jessup and Baheer, 1990). Cold disinfestation is not favoured for domestic trade because of the length of treatment time and the damage to some commodities (Jessup et al., 1998b). Cold disinfestation was particularly well suited to sea transport over long distances when the long treatment period is no inconvenience (O'Loughlin, 1964). The use of cold disinfestation is currently recognised Australia wide and many countries recognise cold treatment as a stand-alone disinfestation treatment. Some commodities do not respond well to cold treatments and become less marketable. Other disinfestation treatments may need to be selected.

3.5. Modified atmospheres

Some commodities respond poorly to cold disinfestation or fumigation. Disinfestation treatments in modified atmospheres are a relatively recent development. The combination of heat and low levels of oxygen increased mortality of fruit flies compared with either heat or low oxygen alone (Hallman, 2010). The combination of high carbon dioxide for short periods at low temperatures provided an alternative for stone fruit (Golding et al., 2010, 2012). While heat alone reduced insect survival, heating combined with sealing fruit in polyethylene bags increased the efficacy of the heat treatment (Jessup et al., 1998). Some commodities such as capsicums respond poorly to storage at low temperatures. A short hot water treatment followed by a cool storage was also an effective quarantine treatment (Ekman et al., 2012). This treatment combines high and low temperatures to control immature stages of Qfly. Modified atmosphere treatments are likely to continue to be developed as world consumers demand less pesticide residue in fresh fruit and become increasingly conscious of human health concerns (Dominiak and Ekman, 2013).

3.6. End point inspection

Cannon (1998) reported on the statistical basis for validity of fruit inspection with a 95% confidence level of detection. In 2007, end point inspection became a standard in Interstate Certification Assurance 28 (ICA 28). This requires that a minimum of 600 fruit per cultivar be randomly selected from each load of certified fruit consigned each day. Each fruit in the sample package is to be removed from the package and all surfaces are examined for evidence of fruit fly infestation. This strategy has been used for many years with no fruit fly detections in certified fruit (Lloyd et al., 2010). This can be supported by tests such as the brown sugar flotation test to find fruit fly larvae in crushed fruit pulp (Yee, 2014). This technique is currently under examination in Australia (Balagawi et al., submitted).

3.7. Statistical analysis of risk

Where needed, the statistical level of confidence could be demonstrated using Bayesian or Scenario Tree analysis (Martin et al., 2007; Stanaway et al., 2011; Dominiak et al., 2011e). These techniques allow the analysis of zero detections based on the probability of detecting the pest if it were genuinely present. This technique has been used to support applications for pest freedom following a long period of zero detections (Dominiak et al., 2011e). This method has been used in Australia to declare disease freedom in livestock (Sergeant and Wilson, 2011). As the demand increases to provide pesticide free fruit (Dominiak and Ekman, 2013), options such as statistical analysis are likely to be developed and used. However the larger question remains and that is the issue of the appropriate level of risk. Baker et al. (1993) recognised the disinfestation of infested produce is Probit 9 or that the treatment of infested produce should induce a mortality of 99.9968% of flies treated. However Probit 9 may not be appropriate for a system approach that largely excludes flies and that may not require disinfestation. In the past, single quarantine treatments have assumed a “worst case scenario” in regards to pest levels and treatments were designed to kill 99.9968% of individuals. However such high infestation levels rarely exist. In particular, these levels are highly unlikely where field based systems approaches keep populations are very low levels. The appropriate level of statistical confidence has not yet been defined to predict that a range of activities (a systems approach) have successfully demonstrated that flies are not present and that a Probit (level of treatment) is not required.

4. Conclusions

Increasingly managers of individual production sites and places of production will have to use their knowledge of fruit fly biology and characteristics for their production area. Managers must evaluate which of the control measures or risk mitigation options can be combined to create confidence that their product does not have an unacceptably high risk of infestation. There will be no single control measure that will fit all commodities and all production sites. There are no silver bullets (Lewis et al., 1997).

In Australia, the restricted use of dimethoate and fenthion potentially heralds a new age of research in pest management using a range of measures based on knowledge of the Qfly biology (Dominiak and Ekman, 2013). It also revitalises the use of older measures that were discontinued due to the low cost and high efficacy of dimethoate and fenthion. It also signals the development of new trade protocols to facilitate trade in the absence of dimethoate and fenthion. Exporting communities will have to understand and document the fruit fly systems approach measures at regional, site and place levels using a range of measures across potentially the three levels. This would demonstrate acceptable levels of risk mitigation to importing countries.

Areas of low pest prevalence (Dominiak et al., 2015a,b,c) and systems approach (FAO, 2012) will hopefully offer producers new

measures for fruit production and market access. Drew (1997) briefly reviewed a systems approach to facilitate the export of zucchini from Queensland to New Zealand. Lloyd et al. (2010) reported that area wide management had been successful in the endemic areas of Queensland however this was the result of many years of research. The development of systems approach will take time to become internationally acceptable market access protocols.

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